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# 28-DAY COMPRESSIVE STRENGTH MONITOR CEMENT SAMPLE CM-1

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G.G. Carette* and W.S. Bowman**

## ABSTRACT

A National Strength Monitor Cement has been prepared under the auspices of the Canadian Standards Association Committee on Hydraulic Cements (CSA A5) and the sample is to be made available through the Canadian Certified Reference Materials Project of CANMET. Twenty laboratories across Canada participated in the interlaboratory testing program to characterize the material with respect to its 28-day compressive strength as determined using CSA standard mortar strength test procedures. CCRMP has analyzed the interlaboratory data and the results are presented in this report.

**Keywords:** Cement standards, Interlaboratory tests, Monitor cement, Mortar compressive strength, Sample preparation.

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## INTRODUCTION

A National Strength Monitor Cement has been prepared under the auspices of the Canadian Standards Association (CSA) Committee on Hydraulic Cements. It was packaged by the Canadian Certified Reference Materials Project (CCRMP) who will also look after storage and sales. A Canadian interlaboratory test program was carried out to determine the 28-day compressive strength of mortars incorporating this material using the CSA procedure described in CAN-3-A5-M83. No other property was evaluated. CCRMP performed statistical analysis of the interlaboratory data and the results are presented herein.

## ORIGIN AND PREPARATION OF CM-1

CM-1 is a Type 20 cement obtained from the production of a Canadian cement plant. About one tonne of the material taken from a given production lot was blended at the Ontario Research Foundation laboratories. The blender used was a double cone type with a baffle through the centre of the machine and approximately 45° to the axis, and capable of handling in excess of one tonne of cement. The material was blended in one lot for about an hour which, based on similar experiences, was sufficient to insure adequate homogeneity of the material. The blended material was shipped to CANMET for bagging into 2.5 kg units and packing into plastic containers for distribution by CCRMP. A number of these samples were also used for strength characterization of the material through an interlaboratory test program.

## INTERLABORATORY TEST PROGRAM

Twenty Canadian cement testing laboratories participated in the test program to characterize CM-1 by testing its 28-day compressive strength in mortars. These laboratories are listed herewith alphabetically. Each was assigned a code number so that analytical results could be recorded while preserving the anonymity of the laboratory. The code number bears no relationship to the alphabetical order of the laboratories.

**Participating Laboratories**

Agriculture Canada (PFRA), Saskatoon, Sask.
Inland Cement Limited, Edmonton, Alta.
Inland Cement Limited, Regina, Sask.
Inland Cement Limited, Winnipeg, Man.
Lafarge Canada Inc., Bath, Ont.
Lafarge Canada Inc., Brookfield, N.S.
Lafarge Canada Inc., Kamloops, B.C.
Lafarge Canada Inc., Montreal, Que.
Lafarge Canada Inc., Sherwood Park, Alta.
Lafarge Canada Inc., St. Constant, Que.
Lafarge Canada Inc., Vancouver, B.C.
Lafarge Canada Inc., Woodstock, Ont.
Ministry of Transportation and Communications of Ontario, Downsview, Ont.
Miron Inc., Montreal, Que.
North Star Cement Limited, Corner Brook, Nfld.
Ontario Hydro, Toronto, Ont.
St. Lawrence Cement Company, Beauport, Que.
St. Lawrence Cement Company, Joliette, Que.
St. Marys Cement Corp., Bowmanville, Ont.
St. Marys Cement Corp., St. Marys, Ont.

Two samples of the homogenized material were sent to each of the participating laboratories who were asked to test the compressive strength of mortar cubes as per CAN3-A5-M83. For each of the two samples provided, they were asked to perform two sets of strength determination on two duplicate

mortar batches prepared within a period not exceeding 72 h. Each set of strength determinations was to include three cubes to be broken in compression at the age of 28 days. The two samples were to be tested within a period not exceeding two weeks and, as far as possible, the most experienced operator was to perform the tests. All tests were to be carried out using a constant water-to-cement ratio of 0.485.

All twenty participating laboratories completed the four sets of strength determinations as requested. The received data was submitted to CCRMP for evaluation.

## STATISTICAL EVALUATION OF THE TEST DATA

The test data, their means and standard deviations are reported in Table 1. They are also plotted in Fig. 1. The "x" in Fig. 1 represent measurements on the first test sample while the "+" are for measurements on the second sample. It is readily apparent from the figure that several laboratories got significantly different results from the two samples. A significant difference between samples was confirmed by a statistical test using a two-way ANOVA (1). Because of the blending which had been done, it was felt that the observed sample differences were not likely due to inhomogeneity but, rather, to slight variations in the test procedure. It was also felt that the differences were negligible compared to the between-laboratory variations. There was no evidence of outlying results, either in terms of high variance or in being remote from the consensus. Thus all data were used for computations. A one-way analysis of variance technique (ANOVA) was used to estimate the consensus value and its variance. This technique assumes that the test data are a sampling of a universal set of results. They are assumed to fit the following model (1):

$$x_{ij} = \mu + y_i + e_{ij}$$

where $x_{ij}$ = the $j^{th}$ result in set i

$\mu$ = the true consensus value

$y_i$ = the discrepancy between the mean of results in set i ($\bar{x}_i.$) and $\mu$, and

$e_{ij}$ = the discrepancy between $x_{ij}$ and $\bar{x}_i.$

It is assumed that both $y_i$ and $e_{ij}$ are normally distributed with means of zero and variances of $\omega^2$ and $\sigma^2$, respectively. The value of $\sigma^2$ is estimated by the within-set mean square, $s_1^2$ and $\omega^2$ is estimated from the difference between the between-set mean square, $s_2^2$, and $s_1^2$

$$\omega^2 = (k-1)\bullet(s_2^2 - s_1^2) \;/\; (\sum_i^k n_i - \sum_i^k n_i^2 / \sum_i^k n_i)$$

The consensus value is estimated by the overall mean, $\bar{x}..$

$$\bar{x}.. = \sum_i^k \sum_j^{n_i} x_{ij} \;/\; \Sigma\, n_i.$$

where $n_i$ = the number of results in set i and

k = the number of sets.

**ANALYSIS OF VARIANCE TABLE**

| Source | D.F. | Sum of Squares | Mean Squares |
|---|---|---|---|
| Between Sets | k-1 | $\sum_i^k n_i\,(\bar{x}_i. - \bar{x}..)^2$ | $\sum_i^k n_i\,(\bar{x}_i. - \bar{x}..)^2 \;/\; (k-1)$ |
| Within Sets | $\sum_i^k n_i - k$ | $\sum_i^k \sum_j^{n_i} (x_{ij} - \bar{x}_i.)^2$ | $\sum_i^k \sum_j^{n_i} (x_{ij} - \bar{x}_i.)^2 \;/\; (\sum_i^k n_i - k)$ |
| **TOTAL** | $\sum_i^k n_i - 1$ | $\sum_i^k \sum_j^{n_i} (x_{ij} - \bar{x}..)^2$ | |

The variance of the overall mean is given by

$$V[\bar{x}..] = (\sum_i^k n_i^2 / (\sum_i^k n_i)^2)\ \omega^2 + (1/\sum_i^k n_i)\ \sigma^2$$

and the 95% confidence limits for $\bar{x}..$ are

$$\bar{x}.. \pm t_{0.975,\ (k-1)} \sqrt{V[\bar{x}..]}$$

The 95% confidence limits are the limits within which the overall mean is expected to fall 95% of the time if the program were repeated many times.

CCRMP has adopted a criterion for certification (2) based on the ratio of average between-laboratory to within-laboratory standard deviation, $\sigma_B/\sigma_A$, where

$$\sigma_B = \sqrt{\sum_i^k (\bar{x}_i. - \bar{x}..)^2 / (k-1)}\ , \text{ and}$$

$\sigma_A$ is the unweighted average of the laboratory standard deviations in Table 1. $\sigma_A$ is numerically equal to $s_1$ provided that each laboratory reports the same number of replicates, as is the case here.

The acceptable upper limit for $\sigma_B/\sigma_A$ is 3. The criterion for certification is that the rejection percentage, RP, i.e., the percentage of sets of results that must be rejected to yield a value of $\sigma_B/\sigma_A$ equal to or less than the acceptable upper limit, shall not exceed 15%. In the present case, an RP value of 0 was obtained with a $\sigma_B/\sigma_A$ ratio of 1.76.

The recommended value of 28-day compressive strength and other statistical parameters are reported in Table 2. Since the criteria for certification for a CCRMP reference material have been met, CM-1 will be made available for purchase as a reference monitor cement.

## REFERENCES

1. Brownlee, K.A. Statistical Theory and Methodology in Science and Engineering; John Wiley and Sons, Inc.; New York; 1960.

2. Steger, H.F. "A re-assessment of the criteria for certifiability in CCRMP"; Geostandards Newsletter 6:1:17-23; 1982.

**Table 1. CSA/CCRMP Monitor Cement CM-1 - 28-day Compressive Strength of Mortars**

| Lab Code No. | Strength*, MPa | | | | Mean | S.D. |
|---|---|---|---|---|---|---|
| | Sample A | | Sample B | | | |
| | Batch 1 | Batch 2 | Batch 1 | Batch 2 | | |
| Lab-1 | 41.0 | 40.5 | 41.8 | 40.6 | 40.98 | 0.59 |
| Lab-2 | 41.3 | 40.9 | 40.3 | 41.0 | 40.88 | 0.42 |
| Lab-3 | 38.8 | 40.5 | 38.4 | 38.0 | 38.93 | 1.10 |
| Lab-4 | 36.1 | 37.2 | 38.9 | 39.6 | 37.95 | 1.59 |
| Lab-5 | 41.7 | 41.9 | 42.1 | 42.0 | 41.93 | 0.17 |
| Lab-6 | 41.4 | 41.0 | 41.4 | 39.0 | 40.70 | 1.15 |
| Lab-7 | 41.8 | 40.6 | 40.2 | 41.4 | 41.00 | 0.73 |
| Lab-8 | 40.2 | 43.3 | 39.6 | 41.5 | 41.15 | 1.64 |
| Lab-9 | 44.6 | 44.1 | 41.2 | 40.1 | 42.50 | 2.19 |
| Lab-10 | 42.7 | 43.3 | 43.3 | 42.7 | 43.00 | 0.35 |
| Lab-11 | 39.5 | 38.6 | 41.6 | 39.7 | 39.85 | 1.26 |
| Lab-12 | 46.4 | 44.8 | 44.3 | 43.5 | 44.75 | 1.22 |
| Lab-13 | 40.1 | 42.0 | 42.0 | 42.1 | 41.55 | 0.97 |
| Lab-14 | 41.2 | 42.1 | 44.0 | 44.0 | 42.83 | 1.41 |
| Lab-15 | 44.5 | 43.3 | 43.3 | 42.8 | 43.48 | 0.72 |
| Lab-16 | 40.0 | 38.9 | 38.6 | 39.1 | 39.15 | 0.60 |
| Lab-17 | 40.4 | 41.3 | 40.5 | 39.9 | 40.53 | 0.58 |
| Lab-18 | 39.6 | 40.0 | 40.7 | 39.5 | 39.95 | 0.54 |
| Lab-19 | 43.8 | 42.8 | 42.7 | 43.2 | 43.13 | 0.50 |
| Lab-20 | 38.8 | 38.2 | 41.9 | 40.7 | 39.90 | 1.71 |

*Each value is the average strength of 3 mortar cubes

**Table 2. Recommended Value and Associated Statistical Parameters for CSA/CCRMP Monitor Cement CM-1 - 28-day Compressive Strength of Mortars**

| | |
|---|---|
| No. of Laboratories | 20 |
| No. of Sets of Results | 20 |
| Recommended Value | 41.2 MPa |
| 95% Confidence Limits | |
| Low | 40.4 MPa |
| High | 42.0 MPa |
| $\sigma$ | 1.1 MPa |
| $\omega$ | 1.6 MPa |
| Certification Criterion | 1.76 |
| Rejection Percentage | 0.0 |

**ANALYSIS OF VARIANCE TABLE**

| Source of Variation | D.F. | Sum of Squares | Mean Square |
|---|---|---|---|
| Between Sets | 19 | .22248800E+03 | .11709895E+02 |
| Within Sets | 60 | .73330000E+02 | .12221667E+01 |
| **TOTAL** | 79 | .29581800E+03 | |

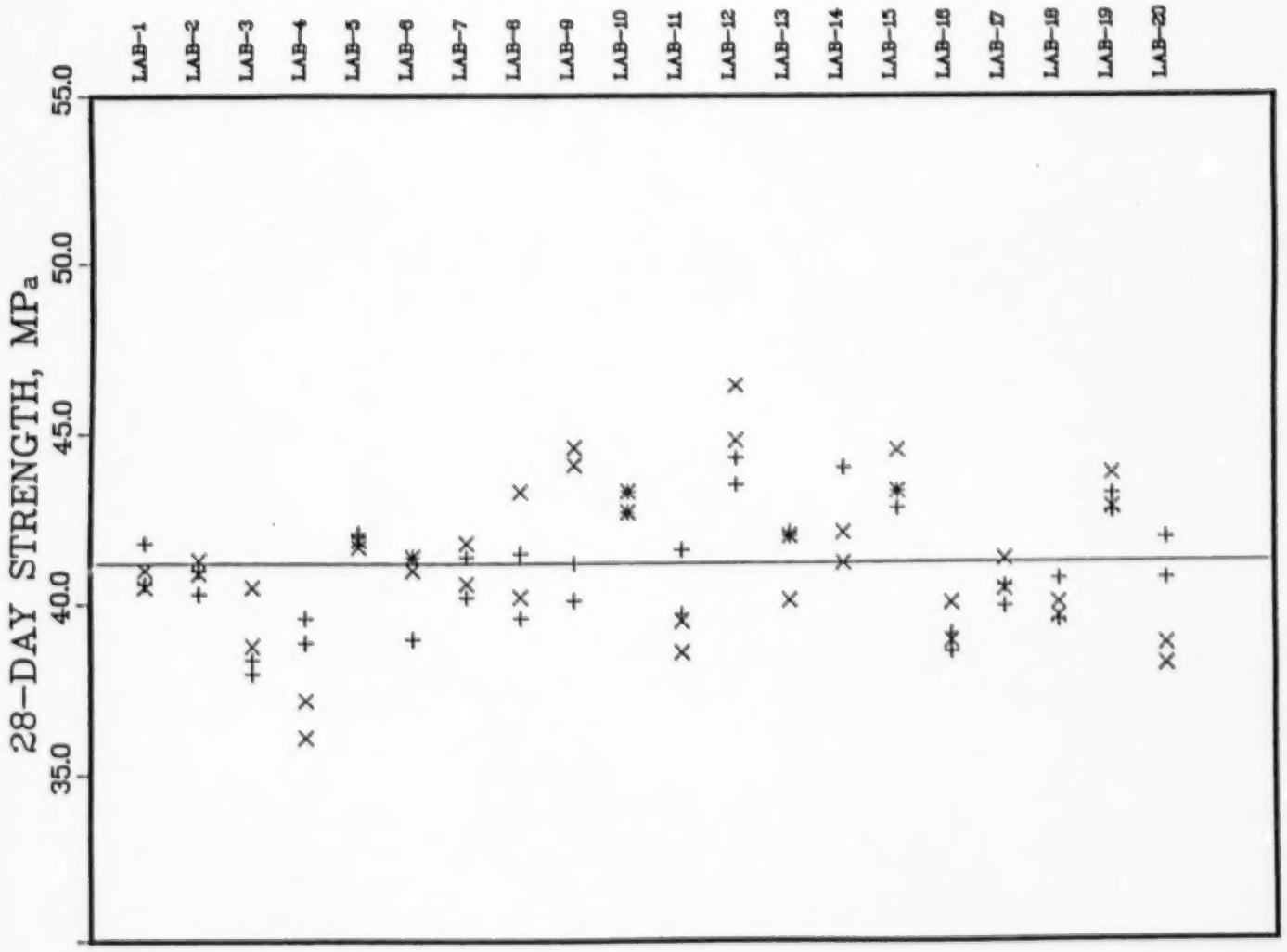


Fig. 1. CSA/CCRMP Monitor Cement CM-1 - Interlaboratory Test Results.